

Chemical Analysis of Particle Size
Fractions from Glass Melting Furnaces

Battelle Columbus Labs., OH

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Feb 81



U.S. Department of Commerce
National Technical Information Service

NTIS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

FP81-160889

TOP OF
IMAGE
AREA

EPA 600/2-81-015
February 1981

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

CHEMICAL ANALYSIS OF PARTICLE SIZE
FRACTIONS FROM GLASS MELTING FURNACES

by

E. D. Spinosa and R. A. Holman
Battelle Columbus Laboratories
Columbus, Ohio 43201

Contract No. 68-03-2552 (T2009)

Project Officer

Charles H. Darwin
Industrial Pollution Control Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

BEGIN
LAST LINE
OF TEXT

RIGHT
MARGIN
LEFT
MARGIN
RIGHT
MARGIN
LEFT
MARGIN

TECHNICAL REPORT DATA <i>(Please read Instructions on the reverse before completing)</i>		
1. REPORT NO. EPA-600/2-81-015	2.	3. RECIPIENT'S ACCESSION NO. PB81 160889
4. TITLE AND SUBTITLE Chemical Analysis of Particle Size Fractions From Glass Melting Furnaces	5. REPORT DATE FEBRUARY 1981 ISSUING DATE.	
	6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) E. D. Spinoso and R. A. Holman	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Battelle Columbus Laboratories 505 King Street Columbus, Ohio 43201	10. PROGRAM ELEMENT NO. 1AB604	
	11. CONTRACT/GRANT NO. 68-03-2552	
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Final, January 1980	
	14. SPONSORING AGENCY CODE EPA600/12	
15. SUPPLEMENTARY NOTES		
16. ABSTRACT The purpose of this research was to identify the size fraction distribution of the various chemical constituents of glass furnace emissions. This would assist researchers in identifying emissions characteristic of glass furnaces; thus, providing design requirements for control technology development programs. The analysis included mass of particulate emissions, particulate size distributions, and analysis of trace metals concentrations in each size fractions.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Exhaust Emissions Particle Size Trace Metals Pollutions Size Fractions		
18. DISTRIBUTION STATEMENT Release to the Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 42
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
CHOOSE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTION
HERE

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related polluttional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of the most toxic and/or most prevalent species in the particulate catch from glass melting furnaces. This study has been conducted to provide quantitative information of the particle size distribution of emitted particulate matter and to evaluate present air pollution control systems to control these emissions. Further information on this subject may be obtained from the Metals and Inorganic Chemicals Branch, Industrial Pollution Control Division, U. S. Environmental Protection Agency.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati, Ohio

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM OF
IMAGE AREA
BEGINNING
FOR TABLE
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

ABSTRACT

The stages of Andersen Cascade impactors used to obtain particle size distribution information from glass melting furnaces have been chemically analyzed for the most prevalent and/or most toxic species. This data has been obtained for both soda-lime and electronic (lead) glass furnaces. A review of applicable control technology has also been conducted.

For furnaces melting soda-lime glasses, the most prevalent and/or most toxic species are Na, Ca, Se, Cr, and Pb. Except for Pb, these elements are expected because they comprise either major portions of the raw material input or are reaction products from the attack of the checker refractory by the hot vapors. The presence of Pb is entirely unexpected and unexplained because neither the raw material feed nor the products of reaction between refractories and vapors can provide a reasonable source for this element. The distribution for Na, Ca, Se, and Pb generally parallel the distribution of particle sizes, indicating that these elements are equally distributed throughout the particulate emissions from these furnaces. For furnaces that melt flint and amber soda-lime glasses, the distribution of Cr also parallels that of particulate size. Green soda-lime glass furnaces, which have significant amounts of Cr in the raw material feed, have a concentration of Cr species in the finer portion of the particulate emission.

For furnaces melting electronic (lead) glasses, the most prevalent and/or most toxic species are Na, Ca, Pb, As, Sb, and Cr. All of these elements, except Cr, are present in the raw material feed. However, the presence of Cr is not unexpected, since Cr is produced by the attack of the checker refractories by hot vapors. The distribution of Na and Ca parallels that of the particle size implying that these elements are evenly distributed throughout the particulate emission. The remaining elements, Pb, As, Sb, and Cr, are slightly concentrated in the smaller size fractions.

The capture efficiency of baghouses, wet collectors, dry collectors, and electrostatic precipitators (ESP) has been estimated as it relates to the size distribution of particulates emitted by glass melting furnaces. The ESP seems to be the best collection device and baghouses may also be useful. The wet and dry collectors are deemed to be inadequate for the control of fine particulate emissions from glass furnaces.

This study made no attempt to determine the compound form of the emitted elements. To conclude from this work that dangerous species are emitted (i.e., free metals) is premature. Suggestions for refinement of this information are set forth.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
(OUTSIDE
DIMENSIONS
FOR TABLES
AND ILLUSTRATIONS)

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

This report is submitted by Battelle Columbus Laboratories in fulfillment of Contract No. 68-03-2552 (T2009) under the sponsorship of the U. S. Environmental Protection Agency. It covers the period March, 1978, through March, 1979. This report is a supplement to a previous report, "Summary Report on Emissions from the Glass Manufacturing Industry", (EPA-600/2-79-101).

DROPPED
HEAD
BEGIN
SECTIONS
HERE

BEGIN
LAST LINE
OF TEXT

SYSTEM OF
UNITS AREA
OUTSIDE
DIVISION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

CONTENTS

Foreword	iii
Abstract	iv
Figures	vii
Tables	viii
1. Introduction	1
2. Objective	2
3. Research Approach	3
4. Results and Discussion	4
5. Influence of Control Technology	24
6. Conclusions	30
7. Recommendations	31
References	32

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM OF
IMAGE AREA
TAKE THIS
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

ADJUST
TO PAGE

TOP OF
PAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

FIGURES

<u>Number</u>		<u>Page</u>
1	Distribution of sodium and particulates for clear soda-lime furnaces	14
2	Distribution of calcium and particulates for clear soda-lime furnaces	15
3	Distribution of selenium and particulates for clear soda-lime furnaces	16
4	Distribution of lead and particulates for clear soda-lime furnaces	17
5	Distribution of chrome and particulates for clear soda-lime furnaces	18
6	Distribution of chrome and particulates for a green soda-lime furnace.	19
7	Distribution of Na, Ca, Pb and particulates from a lead glass furnace	22
8	Distribution of Cr, As, Sb and particulates from a lead glass furnace	23
9	Collection efficiency of a cyclone (5)	28

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
PAGE AREA
ADJUST
TO PAGE
FOR TABLE
AND FIGURE

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
ON PAGE

TOP OF
PAGE
ALIGN

DROPPED
HEAD
BEGIN
SECTION
HERE

TABLES

<u>Number</u>		<u>Page</u>
1	OES data for a typical clear soda-lime glass	5
2	OES data for an electronic (lead) glass.	6
3	OES data for a typical borosilicate glass.	7
4	Summary of data sources by plant code.	8
5	Distribution of Na from soda-lime furnaces	9
6	Distribution of Ca from soda-lime furnaces	10
7	Distribution of Se from soda-lime furnaces	11
8	Distribution of Pb from soda-lime furnaces	12
9	Distribution of Cr from soda-lime furnaces	13
10	Distribution of elements from an electronic (lead) glass furnace	21
11	Median particle sizes and respirable percentages for each chemical specie from soda-lime furnaces	25
12	Median particle sizes and respirable percentage for the electronic (lead) glass furnace stack.	26
13	Fraction escaping collection by baghouses.	27

BEGIN
LAST LINE
OF TEXT

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CHAPTER
OF PAGE

TOP OF
PAGE
AREA

DRAWING
HEAD
BEGIN
SECTION
HERE

SECTION 1

INTRODUCTION

The emissions of fine particulate matter from glass melting furnaces can pose environmental problems if they contain toxic substances and/or heavy metals. If this emitted particulate matter is in the respirable size fraction (i.e., $\leq 3 \mu\text{m}$), human health problems may arise (1). Emissions from glass melting furnaces have been shown to be very fine (2) in that the median particle diameter lies between $0.59 \mu\text{m}$ and $0.83 \mu\text{m}$. Also, those emissions have been shown to be approximately 83 percent respirable. Optical emission spectroscopy (OES) has shown that the most prevalent species in these emissions are Na, Ca, Se, Pb, and Cr. The presence of these species and the fact that the particulates emitted are very fine prompted the EPA to begin this research effort to develop detailed information about the chemical nature of the particulate matter.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
PAGE AREA
DRAWING
CONTINUED
FROM TOP
PAGE

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

SECTION 2

OBJECTIVE

The objective of this research effort is to provide quantitative analyses of the most prevalent and/or most toxic species in the particulate catch from glass melting furnaces. This quantitative information is to be determined as a function of the particle size distribution of the emitted particulate matter. From this information, an estimate of the probability that some of these species will escape capture by control devices is to be made.

BEGIN
LAST LINE
OF TEXT

SECTION 2
IMAGE AREA
EXTENDING
DOWN
FOR IMAGES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

SECTION 3

RESEARCH APPROACH

In a previous program in which emissions from the glass manufacturing operations were measured, Andersen cascade impactors were used to develop the particle size distributions. Also, during that testing program OES data for the probe, filter, and impinger portions of the EPA Method 5 sampling train were gathered. In this current research effort, that OES data was used to determine the most prevalent and/or most toxic species present in each of the glass melting furnaces tested. With that information, a uniform series of analyses by atomic absorption spectroscopy (AAS) was conducted for each of the stages of the Andersen impactors. These analyses provide quantitative data relating the species present to the particle size distribution.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

SECTION 4

RESULTS AND DISCUSSION

Typical OES results for soda-lime glasses, electronic (lead) glass, and borosilicate glass, are given in Tables 1 through 3. For the soda-lime glass, Na and Ca are the most prevalent elements and Pb, Cr, and Se are the most toxic. The presence of Pb and Cr are somewhat unexpected. A similar review of the OES data for the electronic glass reveals that Na and Ca are again the most prevalent species, while Pb, As, Sb, and Cr are the most prevalent toxic elements. For the borosilicate glass, Na, B, and K are the most prevalent, and no particular toxic species have been identified.

These data indicate that all of the AAS analyses should include Na, Ca, Pb, and Cr. For the electronic glass, the analyses should also include As and Sb. In both cases, K could have been identified as the third most prevalent specie. However, it has been excluded in favor of the more toxic species, Pb, Cr, Sb, As, and Se. Unfortunately for this effort, the Andersen impactors for the borosilicate glass are not available and consequently no further information is available for this glass. The data sources used in this study are given in Table 4.

AAS ANALYSES FOR SODA-LIME FURNACES

The results of the atomic absorption analyses for the soda-lime furnaces are summarized in Tables 5 through 9. These tables give the weight percentage of the species present for the size ranges specified. Size ranges are provided in this instance because the specific particle diameter for each case A-M is determined by the gas flow rate under the test conditions, and for the purposes of clarity in these tables, only a size range is provided. Figures 1 through 5 provide the cumulative distribution for each of the measured elements for the soda-lime glass. Also included in each of these figures is the cumulative percentage plot of the particle size distribution from the original testing program. In Figure 5, the graph for the Cr analyses, Stack A has been excluded because that glass is a green glass that contains a high proportion of chrome as part of the batch input. The particle size distribution and the distribution of the chrome analyses for that stack are shown in Figure 6.

As can be seen in Figures 1 through 4, the distributions for Na, Ca, Se, and Pb parallel the distribution for the particle sizes. The parallel nature of these curves indicates that the elements are equally distributed throughout the particulate catch. A similar parallelism can be seen in the Cr

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLE
AND ILLU-
STRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

TABLE 1. OES DATA FOR A TYPICAL CLEAR SODA-LIME GLASS

Element	ppm in EPA-5 Train		
	Front half	Filter	Back half
Be	<10	<1	<10
Cd	<1,000	<1,100	<1,000
As	<1,000	<1,100	<1,000
V	100	110	<100
Mn	50	<50	<50
Ni	50	<80	<50
Sb	<100	<240	<100
Cr	3,000	2,200	<100
Zn	<1,000	<1,100	<1,000
Cu	100	40	<100
Pb	3,000	2,200	<100
B	<100	135	<100
Li	<1,000	<1,100	<1,000
Ag	100	<10	<10
Sn	100	160	40,000
Fe	1,000	<80	<1,000
Sr	100	300	<100
Na	40,000	180,000	<5,000
K	3,000	28,000	<1,000
Ca	5,000	2,800	<1,000
Si	<5,000	(a)	<5,000
Mg	<1,000	1,650	1,000
Ba	<50	<80	<50

(a) Major constituent in filter composition.

Note: All samples have been corrected for blank.

BEGIN
LAST LINE
OF TEST

SEE FIG. 1
SAND AND
GRAVEL
CONTAINED
IN TUBES
AND LIDS
WASTING

TABLE 2. OES DATA FOR AN ELECTRONIC (LEAD) GLASS

Element	ppm in EPA-5 Train		
	Front half	Filter	Back half
Be	<10	<1	<10
Cd	<1,000	<1,400	<1,000
As	20,000	69,000	<1,000
V	<100	<140	<100
Mn	4,000	<70	<100
Ni	10,000	<70	<50
Sb	4,000	14,000	<100
Cr	50,000	21,000	<100
Zn	<1,000	<1,400	<1,000
Cu	800	35	<100
Pb	100,000	138,000	300
B	<100	1,400	<100
Li	<1,000	<1,400	<1,000
Ag	20	<15	<10
Sn	<100	950	30,000
Fe	150,000	1,300	<1,000
Sr	<100	<120	400
Na	10,000	54,000	40,000
K	80,000	136,000	2,000
Ca	<1,000	3,200	100,000
Si	<5,000	(a)	<5,000
Mg	<1,000	<2,500	1,000
Ba	1,500	<400	250

(a) Major constituent in filter composition.

Note: All samples have been corrected for blank.

TABLE 3. OES DATA FOR A TYPICAL BOROSILICATE GLASS

Element	ppm in EPA-5 Train		
	Front half	Filter	Back half
Be	*	<15	*
Cd	<500	<1,500	*
As	<7,000	15,000	*
V	*	<150	*
Mn	*	<40	*
Ni	*	80	*
Sb	150	500	*
Cr	50	<150	*
Zn	<500	<1,500	*
Cu	100	<30	1,500
Pb	*	<150	*
B	22,000	44,000	200
Li	<1,500	<4,400	*
Ag	25	<15	*
Sn	*	150	1,500
Fe	1,500	75	*
Sr	25	<150	*
Na	74,000	150,000	2,200
K	15,000	44,000	3,500
Ca	1,500	350	20,000
Si	3,000	400	23,000
Mg	2,000	<75	450
Ba	*	<100	*
Al	1,500	150	20,000
Mass, mg	19.6	259.5	2.2

* Data = blank.

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

TABLE 4. SUMMARY OF DATA SOURCES BY PLANT CODE

Code ⁽²⁾	Product	Fuel
A	Green soda-lime containers	#6 Fuel oil
D	Clear soda-lime containers	#6 Fuel oil
E	Clear soda-lime containers	#2 Fuel oil
H	Amber soda-lime containers	#6 Fuel oil
I	Clear soda-lime containers	#6 Fuel oil
J	Clear soda-lime containers	#6 Fuel oil
K	Lead electronic glass	Natural gas
L	Clear soda-lime containers	Natural gas
M	Clear soda-lime containers	Natural gas

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
DIVISION
FOR TABLES
AND FIGURES

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE

TABLE 5. DISTRIBUTION OF Na FROM SODA-LIME FURNACES

Stage	Particle size μm	Weight percent							
		A*	D	E	H	I	J	L	M
0	7.5 - 15.4	8.96	8.80	6.57	7.89	11.50	11.91	9.37	10.49
1	5.0 - 12.0	8.78	1.71	13.13	.97	10.08	10.97	8.29	9.50
2	3.5 - 8.0	8.26	9.21	6.31	8.85	9.38	11.60	10.12	9.17
3	2.2 - 5.5	8.70	2.18	6.57	1.25	8.60	10.66	9.04	9.99
4	1.13 - 3.5	9.04	10.03	7.58	10.06	8.96	11.18	10.45	9.91
5	0.68 - 1.7	10.61	7.44	9.60	10.46	8.39	13.27	10.61	14.78
6	0.55 - 1.1	14.43	35.13	29.04	38.23	13.40	9.93	15.42	13.87
7	0.36 - 0.75	17.57	13.98	12.88	11.99	13.61	11.39	13.85	11.48
8	<(0.36 - 0.75)	13.65	11.53	8.33	10.30	16.08	9.09	12.85	10.82

* See Table 4.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

TABLE 6. DISTRIBUTION OF Ca FROM SODA-LIME FURNACES

Stage	Particle size μm	Weight percent									
		A*	D	E	H	I	J	L	M		
0	7.5 - 15.4	10.83	0.29	12.14	2.33	9.47	11.06	11.61	14.10		
1	5.0 - 12.0	10.67	24.02	13.09	23.04	10.42	10.32	9.16	9.35		
2	3.5 - 8.0	9.87	0.31	12.20	2.92	9.85	12.09	11.61	9.64		
3	2.2 - 5.5	10.35	37.86	12.62	18.28	9.28	11.50	9.29	11.80		
4	1.13 - 3.5	11.94	0.44	13.68	2.97	10.80	12.09	13.11	9.78		
5	0.68 - 1.7	11.78	32.12	12.18	25.47	14.20	11.80	13.25	14.82		
6	0.55 - 1.1	10.03	0.57	8.91	3.69	13.07	11.80	11.75	10.94		
7	0.36 - 0.75	11.94	4.07	12.18	19.01	12.31	10.91	9.97	10.94		
8	<(0.36 - 0.75)	12.58	0.31	2.99	2.28	10.61	8.41	10.25	8.63		

* See Table 4.

BEGIN
FIRST
LINE OF
TEXT
HERE

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

TABLE 7. DISTRIBUTION OF Se FROM SODA-LIME FURNACES

Stage	Particle size μm	Weight percent							
		A*	D	E	H	I	J	L	M
0	7.5 - 15.4	9.60	5.29	12.45	12.90	5.35	7.74	16.36	18.65
1	5.0 - 12.0	11.20	7.65	11.24	13.44	5.21	11.95	14.87	10.36
2	3.5 - 8.0	13.60	7.06	12.85	9.68	9.15	9.14	17.10	10.36
3	2.2 - 5.5	12.00	14.12	14.66	6.99	10.56	16.17	9.67	18.65
4	1.13 - 3.5	6.40	9.41	13.86	10.75	21.83	16.88	14.13	14.50
5	0.68 - 1.7	9.60	15.88	12.25	6.99	17.61	10.55	8.92	6.91
6	0.55 - 1.1	7.20	1.76	8.84	6.99	16.20	13.36	5.58	6.08
7	0.36 - 0.75	5.60	7.65	9.44	6.99	7.75	8.44	5.20	6.91
8	<(0.36 - 0.75)	24.80	31.18	4.42	25.27	6.34	5.77	8.18	7.60

* See Table 4.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
INSIDE
DIMENSIONAL
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

TABLE 8. DISTRIBUTION OF Pb FROM SODA-LIME FURNACES

Stage	Particle size μm	Weight percent							
		A*	D	E	H	I	J	L	M
0	7.5 - 15.4	--	--	--	--	--	--	--	--
1	5.0 - 12.0	0.55	0.98	14.43	1.13	16.99	11.99	6.41	9.43
2	3.5 - 8.0	0.86	1.43	14.43	1.97	11.17	16.10	6.41	9.43
3	2.2 - 5.5	--	--	--	--	--	--	--	--
4	1.13 - 3.5	3.07	3.67	14.43	6.19	11.17	20.55	6.41	9.43
5	0.68 - 1.7	--	--	--	--	--	--	--	--
6	0.55 - 1.1	15.66	58.14	23.71	88.61	33.98	32.53	51.28	35.85
7	0.36 - 0.75	--	--	--	--	--	--	--	--
8	<(0.36 - 0.75)	79.85	35.78	32.99	2.11	26.70	18.84	29.49	35.85

* See Table 4.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

TABLE 9. DISTRIBUTION OF Cr FROM SODA-LIME FURNACES

Stage	Particle size μm	Weight percent									
		A*	D	E	H	I	J	L	M		
0	7.5 - 15.4	--	--	--	--	--	--	--	--	--	--
1	5.0 - 12.0	2.36	5.85	11.15	2.68	4.44	13.02	4.43	6.92		
2	3.5 - 8.0	0.98	2.17	12.10	2.68	4.44	19.53	5.83	7.69		
3	2.2 - 5.5	--	--	--	--	--	--	--	--		
4	1.13 - 3.5	2.36	2.51	13.06	12.75	4.44	22.14	6.99	13.85		
5	0.68 - 1.7	--	--	--	--	--	--	--	--		
6	0.55 - 1.1	13.78	48.49	35.03	73.83	55.56	33.85	51.28	36.92		
7	0.36 - 0.75	--	--	--	--	--	--	--	--		
8	<(0.36 - 0.75)	80.55	40.97	28.66	8.05	31.11	11.46	31.47	34.62		

* See Table 4.

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM LINE
IMAGE AREA
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

DROPPED
HEAD
BEGIN
SECTIONS
HERE

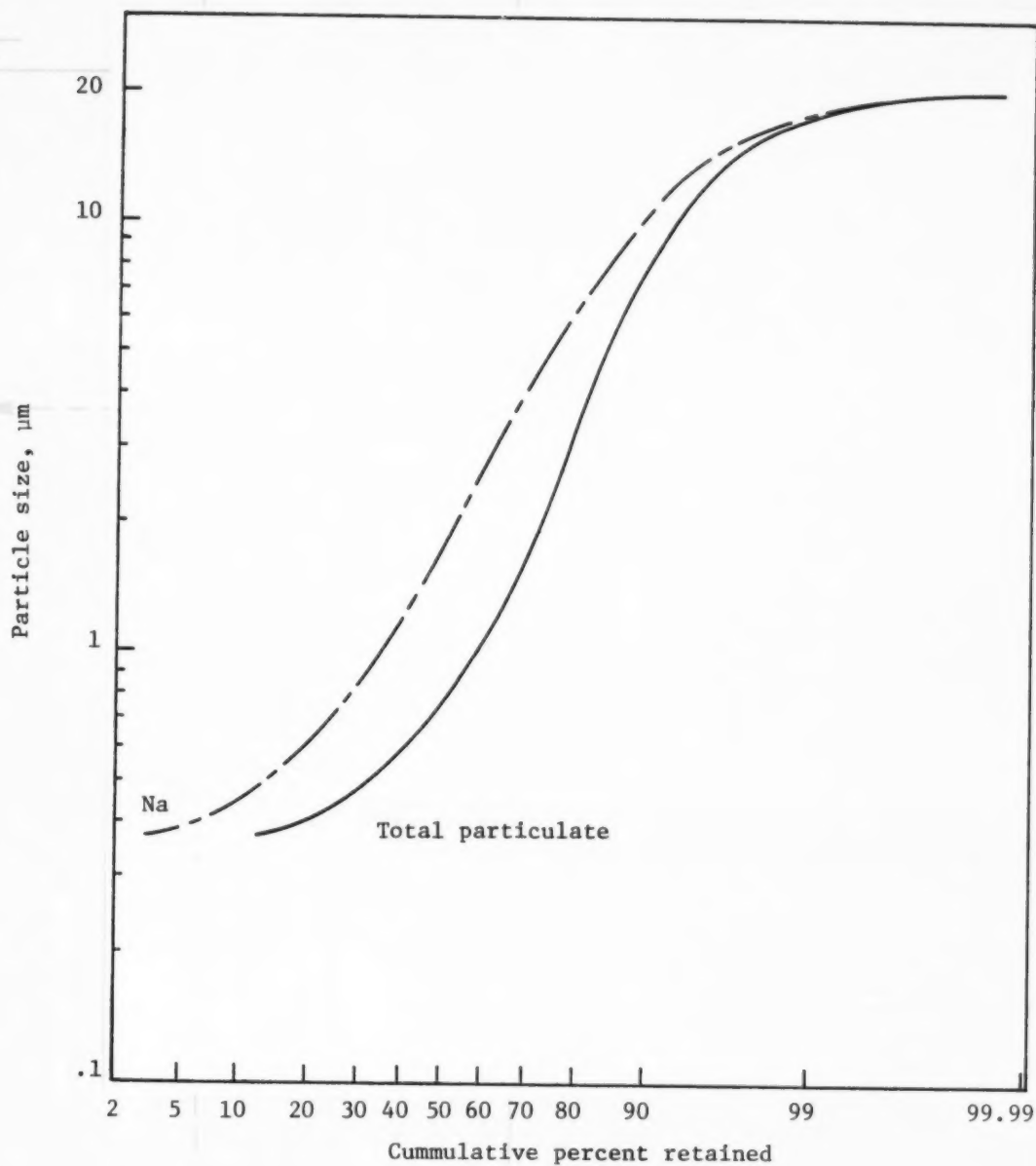


Figure 1. Distribution of sodium and particulates for clear soda-lime furnaces.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSIONS
FOR TABLES
AND OTHER
FIGURES

BEGIN
FIRST
LINE OF
TEXT
HERE

CENTER
BY PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

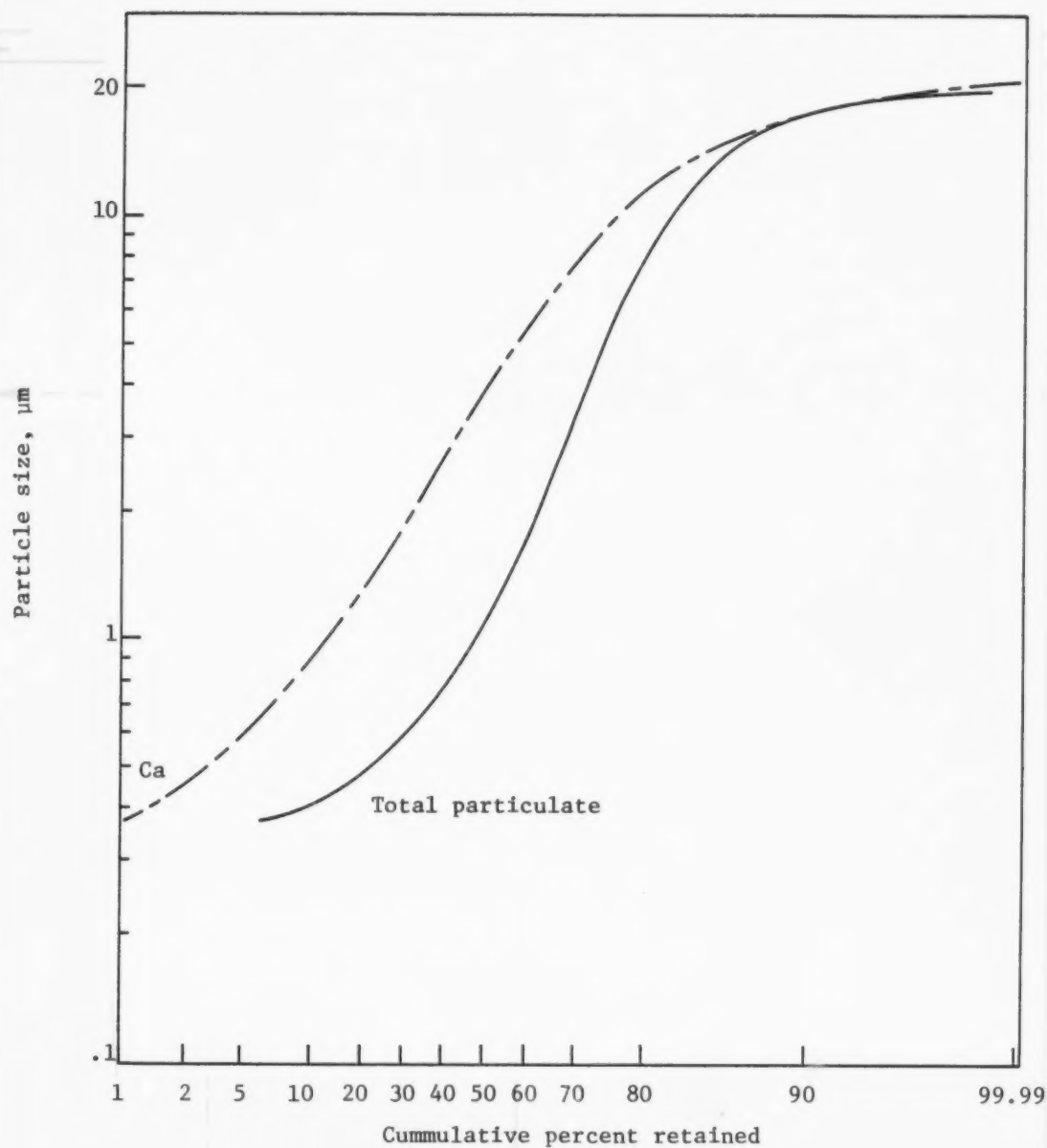


Figure 2. Distribution of calcium and particulates for clear soda-lime furnaces.

BEGIN
LAST LINE
OF TEXT

REVIEW OF
THIS AREA
IS NECESSARY
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

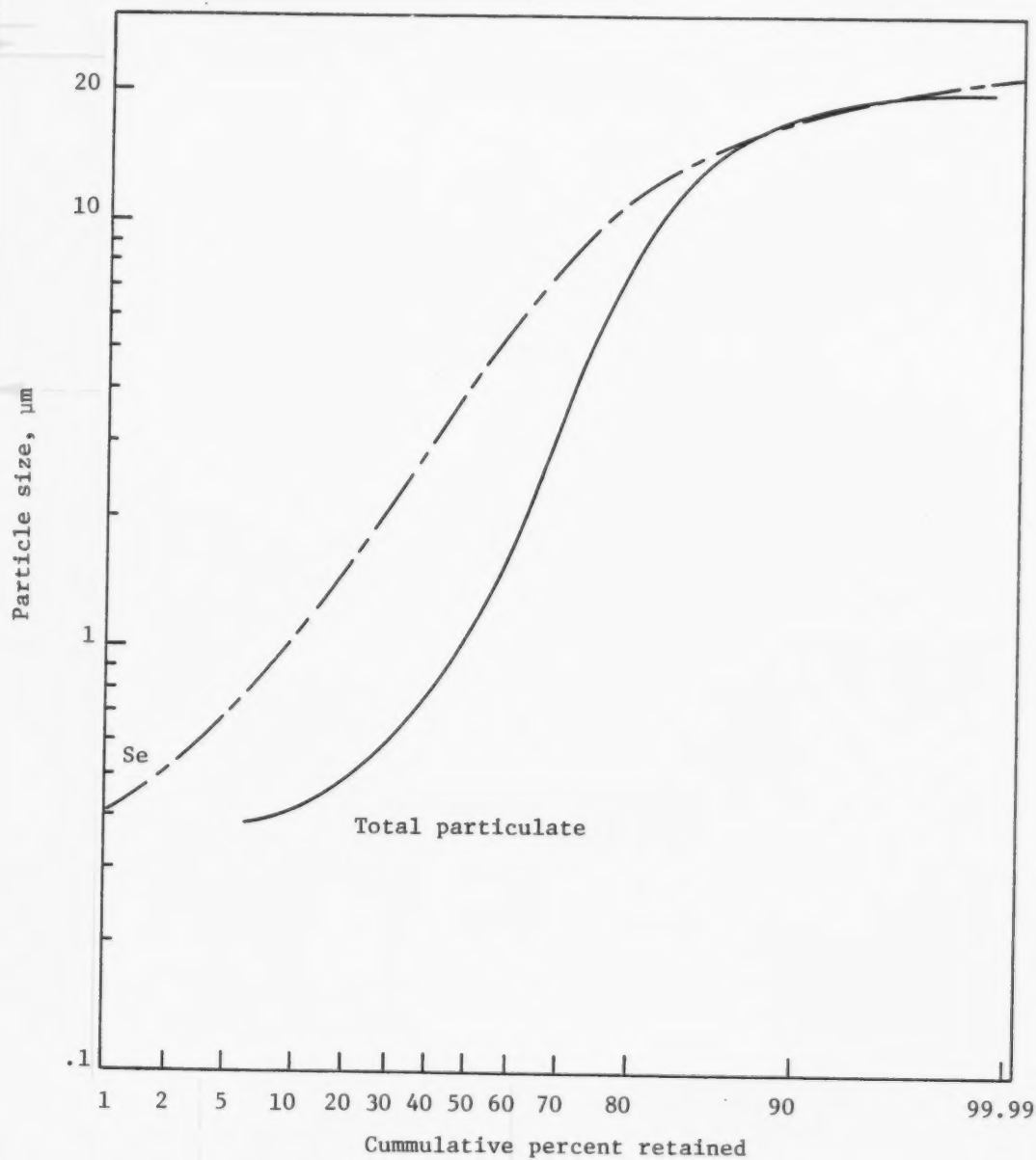


Figure 3. Distribution of selenium and particulates for clear soda-lime furnaces.

BEGIN
LAST LINE
OF TEXT

NOT TO BE
REPRODUCED
WITHOUT
PERMISSION
FOR JARS
AND ILLUS
EXCLUDED

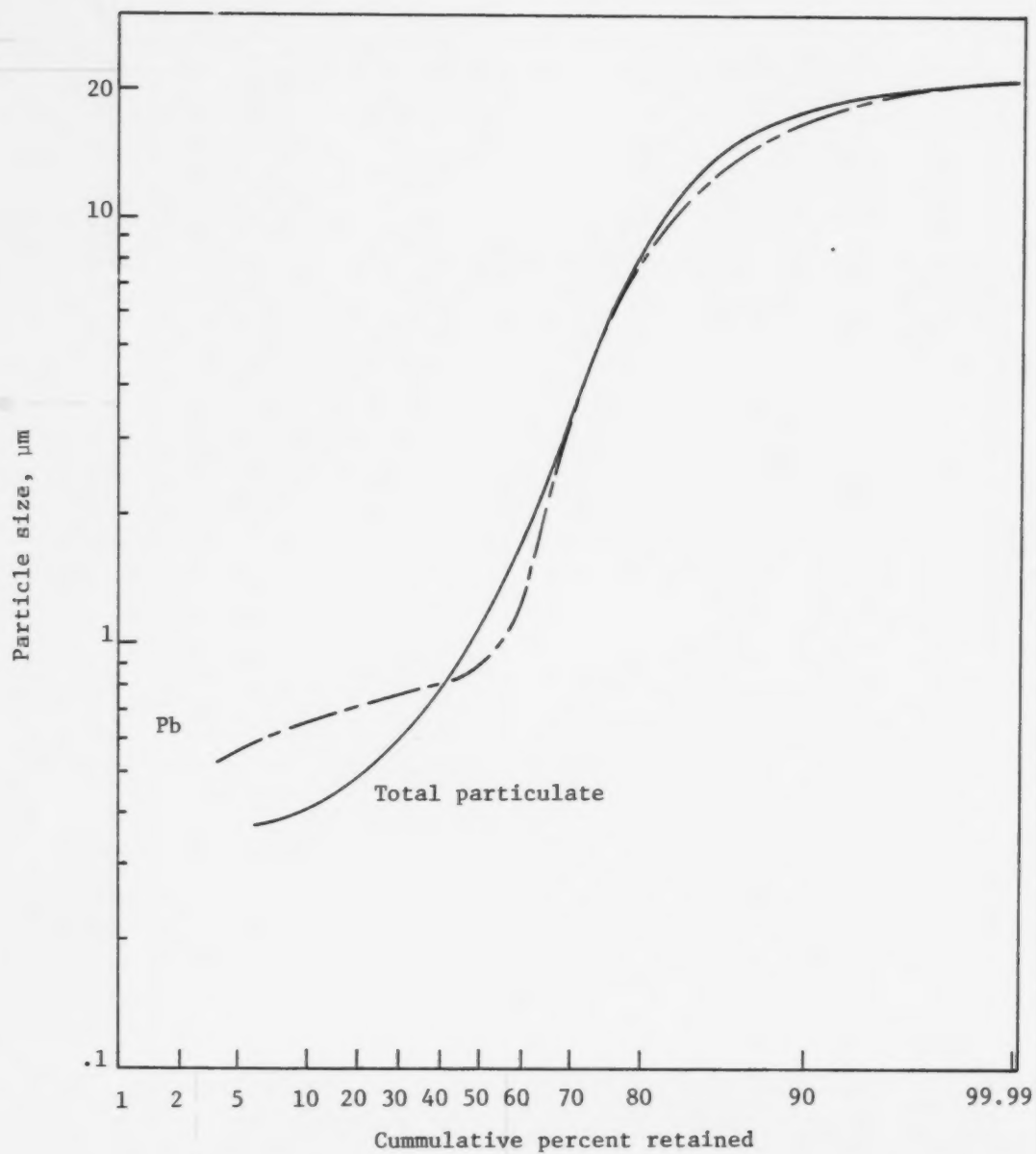
BEGIN
FIRST
LINE OF
TEXT
HEREDROPPED
HEAD
BEGIN
SECTION
HERE

Figure 4. Distribution of lead and particulates for clear soda-lime furnaces.

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

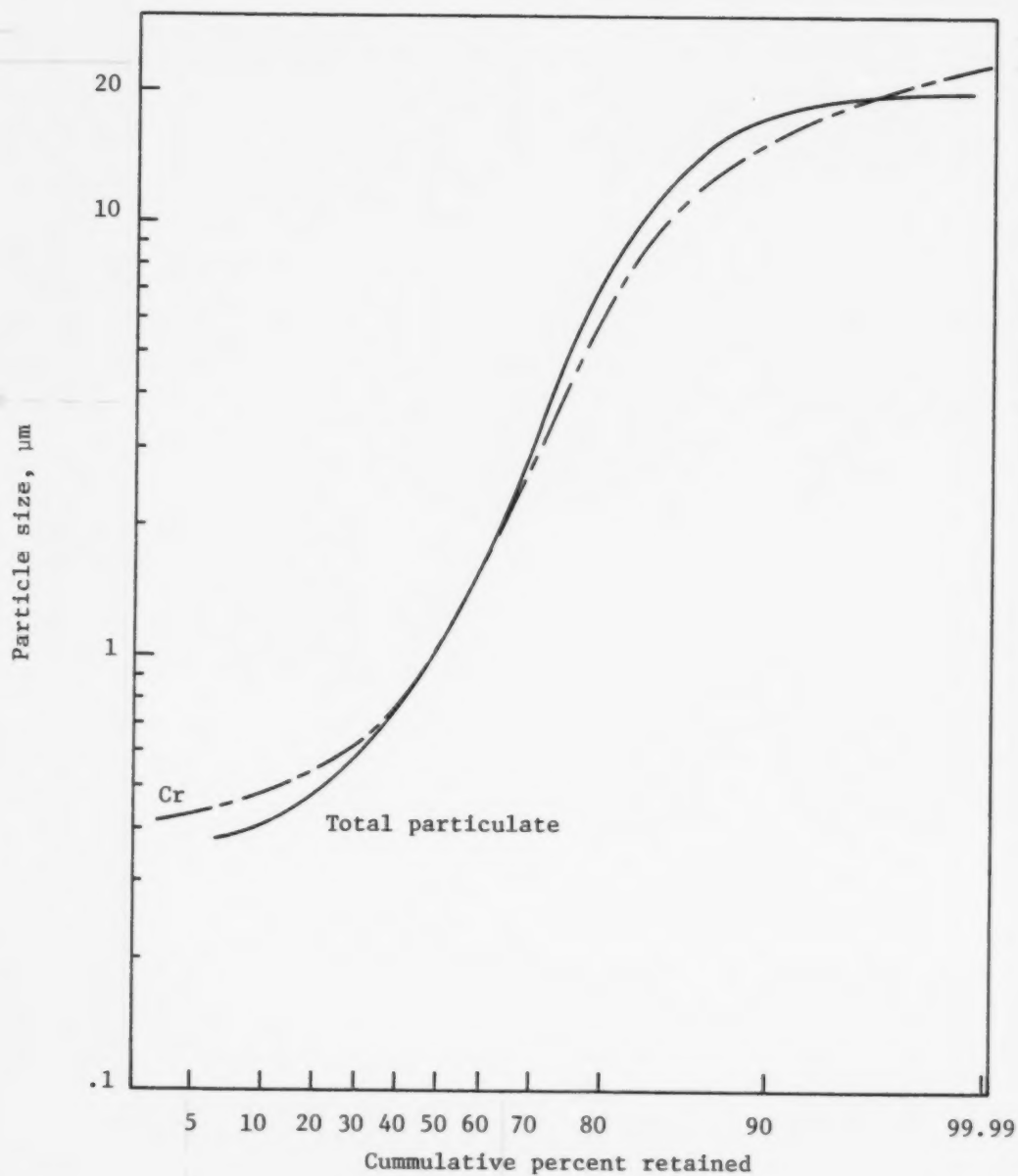


Figure 5. Distribution of chrome and particulates for clear soda-lime furnaces.

BEGIN
LAST LINE
OF TEXT

REPRODUCTION
OF THIS
DOCUMENT
FOR
PERSONAL
USE ONLY
NOT TO BE
REPRODUCED
FOR OTHER
PURPOSES
WITHOUT
PERMISSION
OF THE
NATIONAL
BUREAU OF
STANDARDS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
ON PAGE

TOP OF
PAGE
AREA

DROPPED
HEAD;
BEGIN
SECTION
HERE

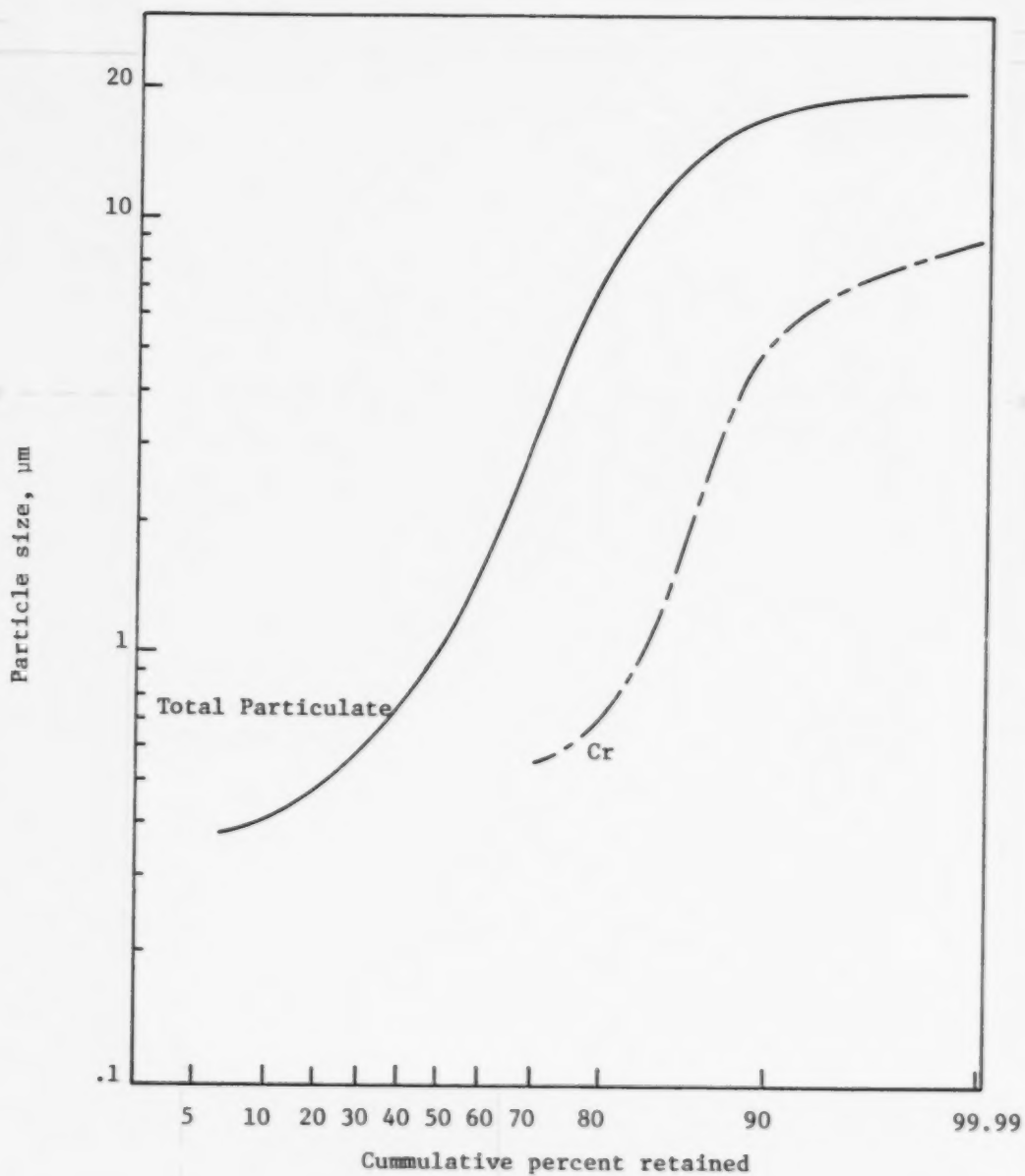


Figure 6. Distribution of chrome and particulates for a green soda-lime furnace.

BEGIN
LAST LINE
OF TEXT

DO NOT
WRITE
OR
DRAW
IN
THIS
AREA

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

analyses for all of the stacks except Stack A, the one for the Cr-bearing glass. Consequently, one can conclude that for flint and amber soda-lime glasses, the concentration of Cr is uniformly distributed throughout the particulate catch. The curves in Figure 6 indicate that the Cr-bearing particulates are concentrated in the smaller particle sizes for Stack A. This concentration is indicative of particulate matter that is generated by the batch carry-over due to impingement by the combustion flames on the loose batch materials.

AAS ANALYSES FOR THE ELECTRONIC (LEAD) GLASS STACKS

The results of the chemical analyses for the electronic glass are shown in Table 10. Also presented in that table are the particle sizes for each of the impactor stages analyzed. Figures 7 and 8 present this data in graphical form, along with the graphical representation of the particle size distributions. As can be seen from these figures, Na and Ca parallel the total particulate curve indicating that these elements are uniformly distributed throughout the particulate catch. The remaining elements, Pb, As, Sb, and Cr, do not parallel the particle size distribution. The information in Figures 6 and 7 indicate that the latter species are concentrated in the finer portions of the particulate catch because the curves generally are lower than that for the particulate catch.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
CONTAINING
TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

TABLE 10. DISTRIBUTION OF ELEMENTS FROM AN ELECTRONIC (LEAD) GLASS FURNACE

Stage	Particle size μm	Weight percent					
		Na	Ca	Sb	Pb	Cr	As
0	20.1	10.34	8.52	0.51	1.13	2.28	1.28
1	12.6	10.03	11.93	--	0.98	--	--
2	8.5	11.11	7.98	0.60	1.49	2.66	1.64
3	5.9	9.93	10.49	--	1.58	--	--
4	4.4	10.62	13.18	0.83	1.53	3.61	2.74
5	1.88	10.62	14.26	--	7.28	--	--
6	1.16	10.42	9.60	1.76	7.80	23.53	17.42
7	.79	10.42	10.49	--	11.98	--	--
8	.79	16.52	13.54	96.30	66.23	67.93	76.92

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLE
AND ILLUSTRATIONS

BEGIN FIRST LINE OF TEXT HERE

DROPPED HEAD: BEGIN SECTIONS HERE

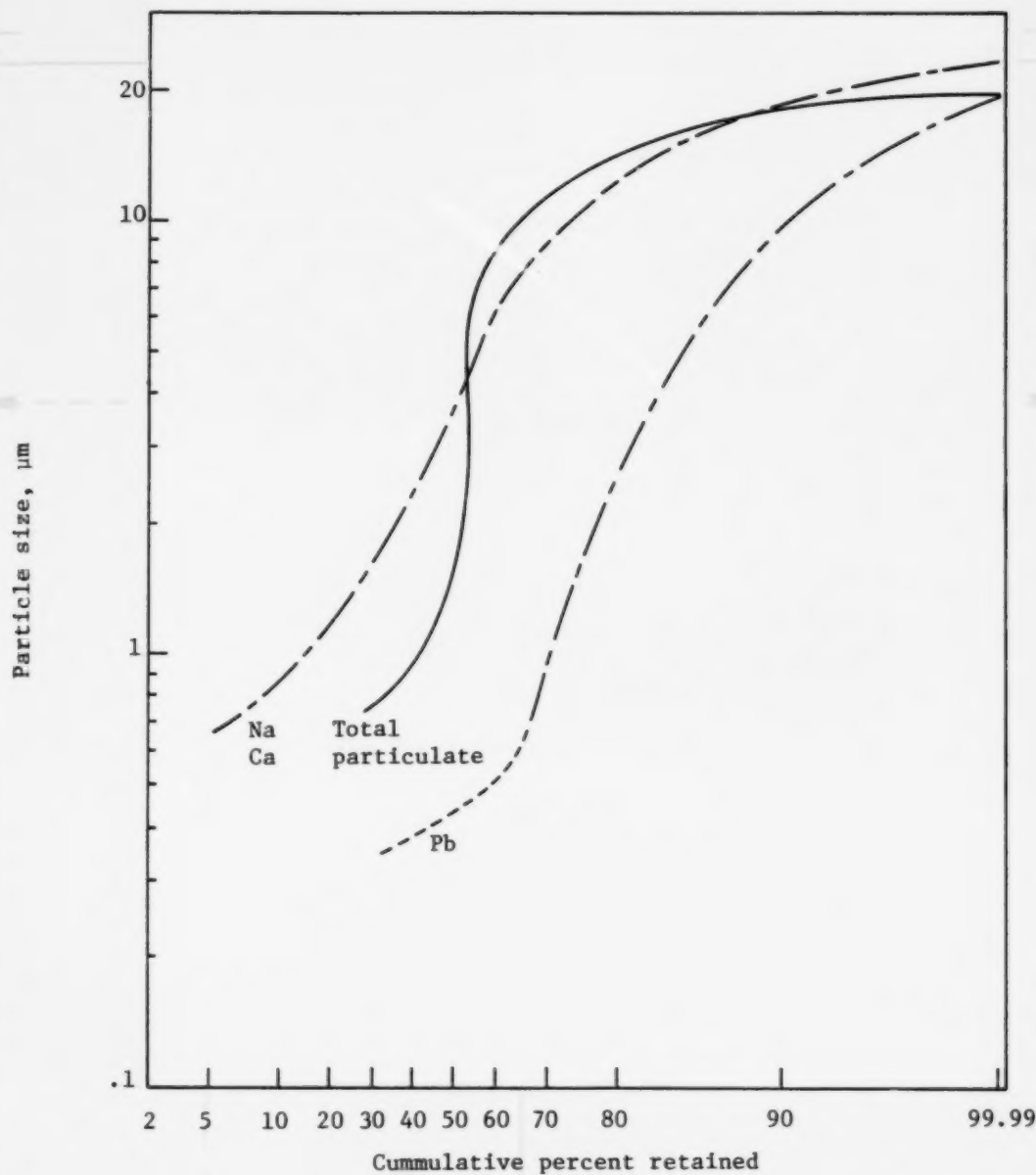


Figure 7. Distribution of Na, Ca, Pb and particulates from a lead glass furnace.

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA
CONTAINS DIMENSIONS FOR TABLES AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

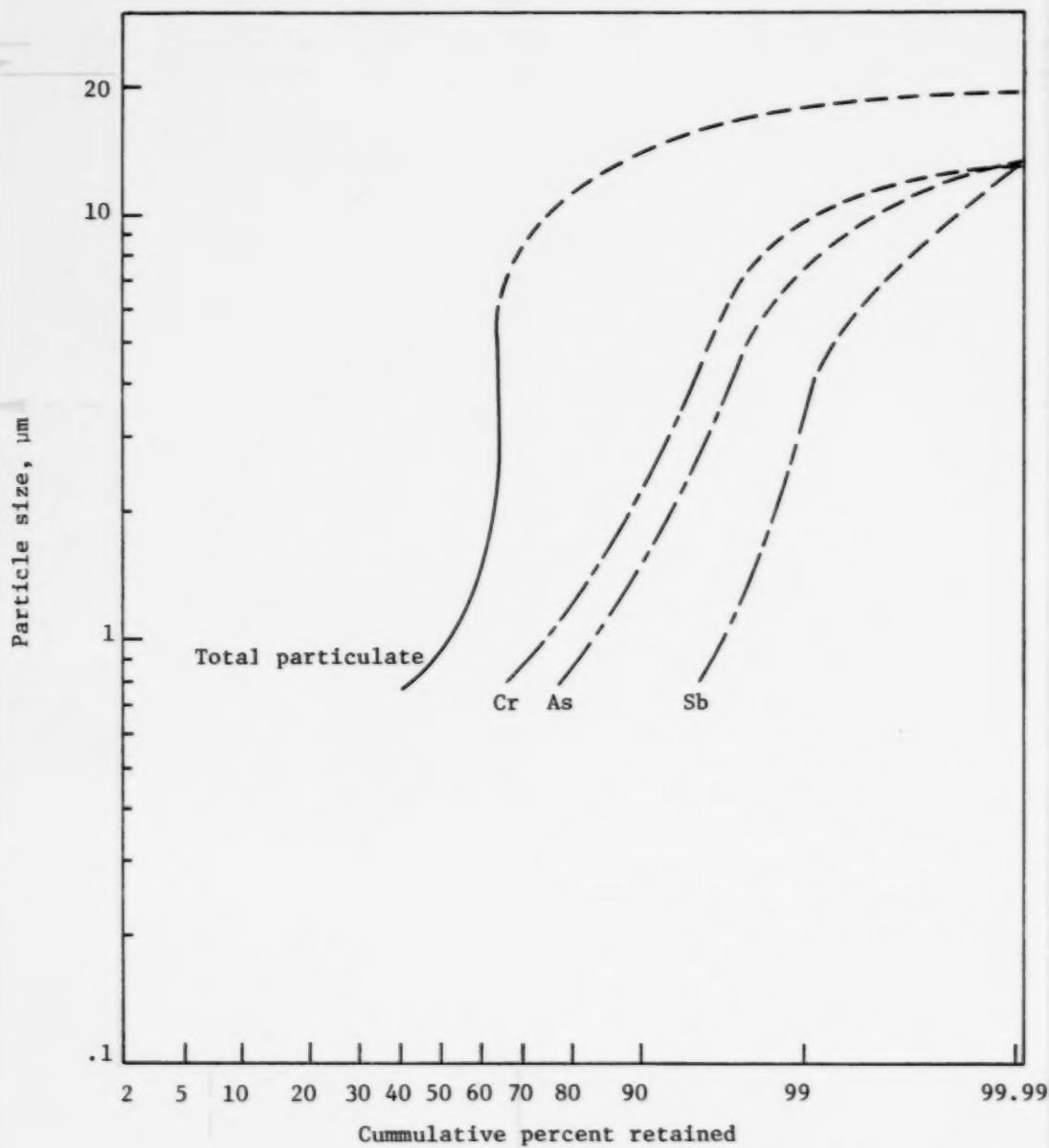


Figure 8. Distribution of Cr, As, Sb and particulates from a lead glass furnaces.

BEGIN
LAST LINE
OF TEXT

WIDTH OF
IMAGE OR
TEXTOR
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

SECTION 5

INFLUENCE OF CONTROL TECHNOLOGY

The control of particulate emissions is important, especially as it pertains to the respirable fraction, that fraction which is 3 μm or smaller. The percentage of the various species in the particulate emissions is of interest especially if these species are concentrated in the portion of the particle fraction that escapes the control device. Tables 11 and 12 contain a summary of the particulate information for the soda-lime and electronic glasses. The data in these tables indicate that the particulate emissions from these furnaces are very fine and that a significant portion of them are in the respirable size fractions. The effect of fine particle size distributions on the efficiency of the usual control devices, such as baghouses, dry collectors, wet collectors, and electrostatic precipitators (ESP) is discussed briefly in this report section.

BAGHOUSES

The efficiency as a function of particle size for baghouses is difficult to assess because many factors such as gas flow rate and particulate loading influence that efficiency. Bethea (3) gives a brief summary that indicates that baghouses are 99 percent efficient above an optimum particle diameter of 0.3 μm . Bethea also notes that the upper temperature limit for baghouses is approximately 370 C. The information in Table 13 indicates that baghouses are very efficient for the particulate matter emitted by glass furnaces because they can remove 90 to 95 percent of the particulate matter depending on the type of glass and the species evolved. However, they do have technical problems created by the high temperature of the gases, approximately 500 C. If baghouses are to be effective, this gas temperature must be reduced so that the bags remain intact. Therefore, the use of baghouses to control emissions from the glass manufacturing furnaces may be limited.

DRY COLLECTORS

The best dry collectors, such as cyclones or multiple cyclones, impingers, etc. are approximately 90 percent efficient if the optimum particle size is 5 μm or greater (4). The efficiency can be plotted as a function of particle diameter (5) for a particulate distribution that is approximately 100 times more coarse (i.e., median diameter approximately 100 μm) than that encountered from glass melting furnaces. As can be seen from Figure 9, the efficiency of collection drops rapidly with decreasing particle size. This

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTION
HERE

TABLE 11. MEDIAN PARTICLE SIZES AND RESPIRABLE PERCENTAGES
FOR EACH CHEMICAL SPECIE FROM SODA-LIME FURNACES

Specie	Median size, μm	Percent respirable ^(a)
Total particulates	0.76	78
Na	1.7	62
Ca	2.6	53
Se	3.0	50
Pb	(b)	(b)
Cr (Flint and clear glasses)	0.72	84
Cr (Green glass)	~0.45	97

- (a) Particle diameter $\leq 3 \mu\text{m}$.
(b) Possible bimodal distribution.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE

TABLE 12. MEDIAN PARTICLE SIZES AND RESPIRABLE PERCENTAGE
FOR THE ELECTRONIC (LEAD) GLASS FURNACE STACK

Specie	Median size, μm	Percent respirable ^(a)
Total particulates	0.92	64
Na	2.3	57
Ca	2.3	57
Pb	<0.6	91
As	<0.8	95
Sb	<0.8	99
Cr	<0.8	93

(a) Particle diameter $\leq 3 \mu\text{m}$.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE

TABLE 13. FRACTION ESCAPING COLLECTION BY BAGHOUSES

Specie	Percent escape*
<u>a. Soda-lime glass</u>	
Total particulate	<10
Na	<5
Ca	<5
Se	<5
Pb	<5
Cr (Flint & amber)	<5
Cr (Green)	<5
<u>b. Electronic (lead) glass</u>	
Total particulate	<10
Na	<10
Ca	<10
Pb	<10
As	<10
Sb	<10
Cr	<10

* Calculated from test results and information in Reference 5.

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLE
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

Particle size, μm

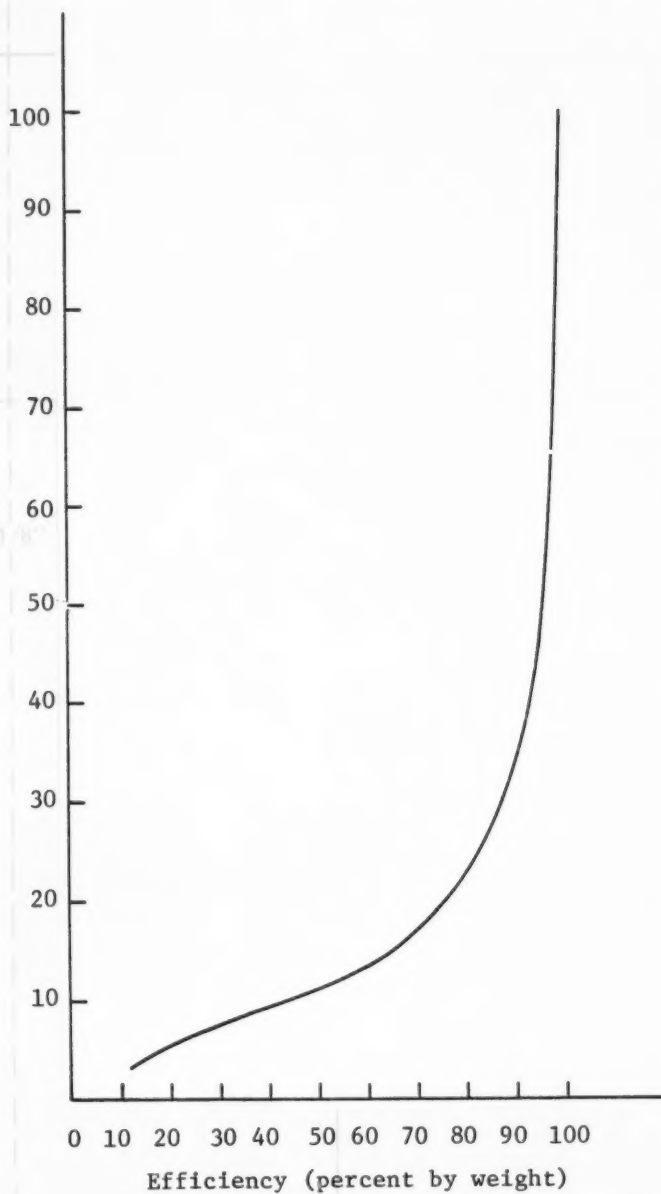


Figure 9. Collection efficiency of a cyclone (5).

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OTHER
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

Typing Guide Sheet

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

rapid drop in efficiency and the large volume of gases that must be handled couple to reduce the usefulness of dry collection systems for glass melting furnaces. With the best information at hand, one can expect that dry collectors will be between 80 and 90 percent efficient or that 10 to 20 percent of the particulates will escape. The portion that escapes capture is expected to be below the respirable limit so that a significant amount of the uncaptured emissions may be concentrated in those particle sizes. Since some of the emitted species (i.e., Pb and Cr) can be concentrated in this respirable fraction, dry collection systems are not expected to be useful in controlling these emissions from glass melting furnaces.

ELECTROSTATIC PRECIPITATORS

The capture efficiency of electrostatic precipitators is a complex function of the plate area, the electric potential between the plates, the dielectric constant of the particulate matter, and the particle size. Bethea (6) indicates that if particle diameter is greater than $0.3 \mu\text{m}$, then the capture efficiency of an ESP is 99 percent. Therefore, ESP's are expected to be an efficient and useful control device for particulate matter from glass melting furnaces. Because flow of large gas volumes can be troublesome, as little as 1 percent and as much as 15 percent of the particulate matter may escape collection. The particle size distributions for most of the analysed metals parallel that of the total particulate catch. In lieu of chemical or physical evidence to the contrary, none of these metals are expected to concentrate in any size fraction of the uncollected matter. However, for green soda-lime glasses and electronic glasses that contain species such as Cr and Pb which concentrate in the finer size fraction, higher emissions of these species may be expected if the efficiency of the control devices is closer to 85 percent than to 99 percent.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
PAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

SECTION 6

CONCLUSIONS

The majority of the species in the particulate emissions from soda-lime glass furnaces are, as expected, Na, Ca, and Se. With the possible exception of Se, these species would normally be expected to occur as the sulfate (8), but the analyzed data did not confirm this expectation. The presence of Cr is not totally unexpected for soda-lime glass furnace emissions because major portions of the bricks used in the regenerators of these furnaces contain chrome which can be attacked by the various species in the high temperature exhaust gases. However, the presence of Pb in emissions from soda-lime furnaces is entirely unexpected because no reasonable source for this element can be postulated. Lead is not part of the input material for this glass composition. The presence of Pb is real because it appears in all of the OES analyses from the previous study, even though it is a very small fraction of the total catch. The most troublesome species is expected to be Cr from melters that produce green soda-lime glass because at least 97 percent of that element is in the respirable portion of the emissions. Nevertheless, control devices are expected to be adequate for the control of emissions from glass melting furnaces. The electrostatic precipitator seems to be the most useful control device because recent data indicates that it can trap a very large portion of the fine particulate emission from glass melting furnace, and it can operate at the high temperatures and large gas volumes that are expected from these operations. However, large gas volumes may cause a reduction in the capture estimate (i.e., approximately 99 percent) to a less optimistic value but the details of that efficiency reduction depend on the specifics of each installation. Baghouses can also provide a means to control particulate emissions from glass melting furnaces, but the severe operating conditions greatly hamper their usefulness. Scrubbers and dry collectors are expected to be inadequate for control of the fine particulate size distributions that will be encountered.

A majority of the species from the electronic (lead glass) are, as expected, those carried over from the input to the melting process. The particular data used in this study is atypical because no regenerators are used on that furnace. Therefore, the conclusions pertinent to particle size generally cannot be applied to most furnaces melting this type of glass. However, the previous arguments about control devices for soda-lime glass furnaces also apply to the lead glass furnaces. In general, control can be accomplished, but the specifics for each installation may pose some difficulties.

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

SECTION 7

RECOMMENDATIONS

This study analyzed only the most prevalent and/or most toxic elements present in the particulate emissions from glass melting furnaces, and it made no attempt to look for the specific form (i.e., compound) of these elements. Since most of these elements are initially present in a combustion zone at approximately 1400 C, the possibility for formation of stable compounds is very large. To conclude that dangerous emissions exist would be incorrect at this juncture because all of the analyzed elements can exist as either oxides or sulfates and in these forms they may not be nearly as dangerous as the free metal form. Therefore, future research in this area should include an attempt to identify the exact character of the compounds present. X-ray diffraction using a Debye-Scherrer camera of the samples collected in a previous research effort, may be useful in establishing the compounds present. If more information is needed, then another sampling program would be required to gather larger volumes of samples to be used in wet chemical analyses. Such analyses would permit determination of all the compounds present.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
BEGIN
SECTION
FOR TABLE
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

REFERENCES

1. Suta, B. E. Human Exposure to Atmospheric Arsenic. Report to U. S. EPA/ORD (Project Officer A. P. Carlin, Contract No. 68-01-4314) from Center for Resource and Environmental System Studies, April, 1978.
2. Spinosa, E. D., Hooie, D. T., and Bennett, R. B., Summary Report on Emissions from the Glass Manufacturing Industry. Report to EPA (Contract No.'s 68-01-3159 and 68-01-4431). EPA-600/2-79-101, April, 1979.
3. Bethea, R. M. Air Pollution Control Technology. Van Nostrand Reinhold Company, New York (1978), p. 18-21.
4. ibid
5. Air Pollution Control Manual, edited by John A. Danielson, Second Edition, Environmental Protection Agency, Research Triangle Park, North Carolina (1973), p. 97-99.
6. ibid, p. 140 and 160
7. loc cit, reference 3
8. High Temperature Chemistry of Inorganic and Ceramic Materials, edited by F. P. Glasser and P. E. Potter (1977), "The Chemical Changes Occurring During the Cooling of Hot Gases from Flat Glass Furnaces" (B. J. Kirkbide), p. 65-79.

BEGIN
LAST LINE
OF TEXT

OPTIONAL
IMAGE AREA
WITHIN
DIMENSION
FOR TABLES
AND ILLUSTRATIONS